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Clove essential oil (*Syzygium aromaticum*) encapsulated in a lignin matrix for controlled release

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Essential oils (EOs) are complex mixtures of naturally derived active compounds extracted from various terrestrial plants. Due to their volatile nature, these compounds readily evaporate under ambient conditions and are prone to oxidation when exposed to heat and sunlight[1]. EOs exhibit a wide range of biological activities, including antioxidant, antimicrobial, antifungal, insecticidal, and anti-inflammatory properties[2,3]. To preserve their functional properties, encapsulation in a polymeric matrix that serves as a physical barrier is an effective strategy. In this study, lignin was extracted via alkaline treatment from persimmon (*Diospyros kaki L.f.*) pruning residues (branches and leaves), offering a sustainable use of agro-industrial waste[4], and clove essential oil (*Syzygium aromaticum*), which has antimicrobial, antioxidant, anti-inflammatory and insecticidal properties[5]. The EO was encapsulated using an antisolvent precipitation method, also referred to as micellization[6]. The resulting nanoparticles exhibited an average diameter of 346,47 ± 11,55 nm, a polydispersity index (PDI) of 0,05 ± 0,03, considered low for natural polymers (PDI < 0,40)[7] and a zeta potential (ZP) of −57,70 ± 3,43 mV, suggesting excellent colloidal stability (ZP < −30 mV)[8]. These findings demonstrate the technical feasibility of using lignin as a biodegradable and cost-effective carrier for the encapsulation and controlled release of clove essential oil. This system holds potential for various applications, including as a natural active agent in cosmetic and therapeutic formulations, or in agroindustrial settings for pest management.

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